MISSOURI RIVER

CHANNEL REGIME STUDIES

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I - INTRODUCTION

This report is prepared as an interim publication designed to introduce a channel regime study of the Missouri River at Omaha, Nebraska and to present the data collected and analyses completed through April 1967.

The study was initiated to investigate the factors influencing periodic shifts in the stage-discharge relation. This phenomenon has been noted in numerous streams, and several instances have been discussed in technical literature (1-2-3, etc.); however, it is particularly important in the Missouri River in respect to the maintenance of navigation depths. Discharge of the river downstream from the Gavins Point Dam, near Yankton, South Dakota, is controlled within reasonably narrow limits by the upstream system of main stem reservoirs, releases from which are coordinated with downstream tributary inflow to maintain or exceed designated minimum flows at several control locations. It would be desirable to control the releases to maintain control depths rather than control discharges, but existing knowledge is not adequate to predict within desirable limits either the occurrence and dimensions of the variable bed forms nor the consequent river stages and the depths from the water surface to the crests of the bed forms.

The controlled flow of the Missouri River at Omaha will vary generally between 30,000 c.f.s. and 35,000 c.f.s. during the navigation season extending generally from mid-March to mid-November, and from 7,000 c.f.s. to 10,000 c.f.s. during the winter period. Large shifts, of as much as two feet in the stage-discharge relation occur seasonally with the stages for a given discharge being generally higher during the early summer and decreasing progressively into the fall months. These shifts, as might be expected, tend to be even more prominent during the intervals when winter flows are being increased to navigation levels or vice-versa. For example, the stages at Omaha for discharge measurements on 21, 22 and 23 March were 5.7, 5.2 and 5.6 feet, respectively, while the discharges for these measurements increased from 23,300 c.f.s. to 27,200 c.f.s. to 30,600 c.f.s.

Because of the apparent seasonal factors, it is necessary that the collection of field data be scheduled for varying times during the year. Additionally, it will be necessary to extend or revise the investigation as indicated by analyses of the data as they are obtained. Thus, the extent, in time, of this study is currently indefinite. Observations to date have been confined to a seven mile study reach (Missouri River miles 609 to 616), including the Ak-Sar-Ben bridge crossing at mile 615.89, as shown on plate 1; however, this concentrated reach study is coordinated with a more general study of the river channel. Data on stages, discharges and temperatures have been assembled from 1956, the first year in which the flows were essentially regulated. Field data for this report were collected from September through November 1966 and during March and April 1967. Further observations are planned to begin in August 1967. The purpose of this report is to summarize current progress and present preliminary conclusions. It is intended that a more conclusive report covering the 1966 and 1967 periods of study will be prepared at a later date.

II - BASIC STUDY DATA

Special field observations included longitudinal profiles of both the channel centerline and thalweg; river cross sections (range profiles) every one-half mile throughout the study reach; water surface profiles; bed surface sampling at alternate ranges, and suspended sediment sampling from the Ak-Sar-Ben bridge.

The longitudinal profiles shown on plates 2-10 were taken, as nearly as possible, along the channel centerline and thalweg for each survey. The general location of these profiles is shown on plate 1. No lateral horizontal control was used to locate these soundings. The black vertical lines, called "Fix Lines," represent identical locations along the river for each survey. The river mileage is shown each one-half mile throughout the reach. The survey date is shown above each profile.

River cross sections were taken at each one-half mile point. These locations are the same as those for which mileages are shown on the longitudinal profiles. The cross section information was programed by electronic computer methods to obtain areas, widths, mean depths, and other hydraulic elements. These results were used to determine several of the hydraulic parameters that are discussed later in the report. The cross sections were plotted but are not included in this report.

Water surface elevations were determined at approximately one mile intervals throughout the reach. These elevations were plotted and the water surface elevation at each range location was determined from this profile. The 19 September 1966 water surface profile was selected as a reference plane to serve as a fixed datum for study of cross section changes. The water surface profiles show an average slope of 0.77 foot per mile with little variation.

Five bed samples were collected at approximately equal intervals across the channel at alternate ranges throughout the study reach. Each set of five samples was composited in the field so that only eight samples had to be analyzed by the laboratory for each survey.

The discharges, stages and rating curve shifts, shown on plates 11, 12, 13 and 14 in hydrograph form, are reported to the Corps of Engineers by the U. S. Geological Survey. These observations at the Ak-Sar-Ben bridge are part of a continuous program. The water temperatures were provided by the Metropolitan Utilities District. These temperature observations were made at the Florence pumping station approximately ten miles above the study reach. Only four (1962, 1964, 1966, and 1967) of the twelve years (1956-1967) for which comparisons were made are included in this report. The 1967 hydrograph sheet shows information for February through April while the other years show information for August through November.

The rating curve shift indicates the variation in the stage discharge relationship. This "shift" is defined as the difference between the stage as read from the U. S. Geological Survey rating curve and the actual recorded stage for a measured discharge. (The vertical distance between a plotted point and the U.S.G.S. rating curve on plate 15.) Plate 15 shows the present (1966) U.S.G.S. rating curve and the plotted points of most of the discharge measurements taken during the period August through November 1966. Plate 16 was included to show the small variation in the U.S.G.S. rating curves for the 1956-1966 period.

Suspended and bed sediment sampling records for Omaha were compared for the years 1958 through 1966. These observations are part of the regular sediment sampling program in which suspended depth-integrated and bed sediment samples are taken at 10 verticals from the Ak-Sar-Ben bridge at about weekly intervals during the open water season. Plates 17 through 22 show these comparisons for the years 1962, 1964, and 1966. The values shown for the suspended sediments are mathematical composites of all depth integrated samples collected on an observation date. Four sets of special samples were collected at this station during the 1966 study period in which point integrated samples, duplicate depth integrated samples, point velocities, and bed sediment samples were collected at five verticals. In addition, other depth integrated samples were also collected at five intervening verticals. The results from these observations have not been completely evaluated and are not included in this report. It is planned to make a detailed study of all special sampling observations that have been made at Omaha since 1955.

It is apparent after evaluating the results of both depth integrated and point integrated sampling, a larger sample volume is necessary. To collect these larger samples, it may be necessary to develop a continuous pumping sampler that will collect sufficiently large samples to adequately define the coarse suspended sediments.

III - ANALYSES OF DATA

Temperature, Stage, Discharge, and Shift Hydrographs. The trends for 11 years of record from 1956 to 1966 are similar. It can be noted that while the discharges remain reasonably steady during the September-November period, the stage and rating curve shift tends to decrease with decreases in water temperature. This trend was true for all eleven years; however, the changes are not entirely consistent. It can be noted, if the shift is plotted against water temperature for a number of years, that the slope and location of these lines are not the same. However, the patterns are similar. This is also true of the summary graph (plate 23) showing the amount of shift, temperature change and variation in discharge. It appears that the time and extent of the shift are determined both by amount of temperature change and the discharge prior to the shift.

Average Cross Sections. Five of the nine observed average cross sections, each representing a specific survey date, are shown on plate 24. Each of these cross sections represents a composite of 15 range profiles measured during each survey. (Each composite was developed, via an electronic computer program, by computing channel widths at one foot increments below the reference plane elevation at each range and then averaging these incremental values.) The very minor changes in the average cross sections should be noted. Such minor changes may result because of the accuracy of the sounding equipment and the location of the dunes at the time of the survey. To further illustrate the range of change that might be expected due to variations in discharge, reach length, and time, five average cross sections for 18 ranges surveyed in 1950 in the Blair to Florence reach are shown on plate 25. This reach extends from 10.2 to 32.4 miles upstream from the Ak-Sar-Ben bridge. The discharge for three of these sections was relatively high (70,000 to 189,000 c.f.s.) while the discharge for the other two was 35,000 and 36,000 c.f.s. The average sections for these lower discharges are comparable to the average sections for the 1966 study reach. To illustrate this comparability, the 8 September 1966 average section for the study reach was added to plate 25.

The mean depths and end areas were also composited for each survey. For comparative purposes, these values are plotted on plate 26. No trends are apparent and it appears that no degradation has occurred. The changes shown may be due to the redistribution of the bed material; i.e., from undulating dune formation to a nearly smooth bed surface.

Channel Hydraulic Characteristics. The average velocity and Manning's "n" values, shown on plate 27, were computed for the reach for each survey. The average velocity is an average of the velocities from all 15 river cross sections. These values were determined by dividing the discharge by the surveyed flow areas. The Manning's "n" values were determined three different ways:

a. The first method was accomplished by averaging the areas, hydraulic radius, etc., at the upstream and downstream ranges of a segment. With the discharge and slope known, Manning's "n" was computed for the segment. This method assumed the energy slope was equal to the water surface slope. The "n" values for all segments were averaged to get the average "n" value for the reach.

b. The second method utilized only the average cross section and the average water surface slope within the study reach. Manning's "n" was then computed using the hydraulic elements of the average cross section.

c. To check the accuracy of these methods, backwater computations were made using the average "n" value for the reach, and also by varying the value for each segment according to the values obtained by the first method.

All of the methods proved to be adequate. Only very minor differences were noted; the maximum difference being about 3 percent. To determine velocities and "n" values for future surveys, it is planned to use only the average cross section.

Channel and Thalweg Longitudinal Profiles. These profiles indicate that the channel bed becomes progressively smoother from the summer into the fall months. It is apparent that the dunes are relatively short and high during the summer and become longer and shallower later in the fall. Much of the bed surface appeared flat at the time of the last two 1966 surveys. As shown above, the discharge remained reasonably steady during the period of the surveys, while the temperature progressively decreased. It would appear, therefore that the observed flattening of the bed is correlated with the temperature decrease. A reverse trend from a smooth bed to rougher conditions can be noted on the 1967 spring profiles. However, as noted from data on plate 14, these bed changes are associated with a sharp increase in discharge as well as a rise in water temperature.

Dune Analysis. The number, height and length of dunes presented on plate 28 were determined by measuring bed undulations on the sounding charts of the channel centerline longitudinal profiles, plates 2 through 4. It is recognized that this single profile is a measurement of only a very small portion of the channel width but it appears representative of the existing channel bed configurations. It can be noted from plate 28 that the dune length and flat bed length both increase from summer to fall. The number of dunes, dune height and dune steepness decrease during the same period. The results of this bed smoothing can be noted in the decrease in flow resistance (Manning's "n"). The average water depth to the top of the dunes (plate 29) increased from summer to fall. Even though the observed water surface profile shifted downward over 1.5 feet, the water depth over the top of the dunes increased. It should be remembered that this evaluation is based on only one profile which is a measurement of a very small portion of the channel width and is an average for the entire length of the study reach. To check whether this average trend is also true for certain short critical locations in the channel, similar determinations were made for the two crossing reaches, mile 612 to 614 and mile 615 to 616. Again, the depth over the top of the dunes increased from summer to fall in each of these reaches. While the trends in the short reaches were similar to the average for the entire survey reach, there is more scatter in the data. These plots are not included in this report. A more detailed study is planned that will include a statistical analysis of these longitudinal profiles and other available sounding data.

Variations in Suspended Sediment Concentrations. The suspended sediment concentrations from depth integrated samples were compared for the years 1958 through 1966. Plates 17, 18 and 19 show the variations in concentrations for various grain sizes during the fall periods of 1962, 1964 and 1966. In interpreting this suspended load data it is pertinent to note from the bed surface grain size analyses on plates 20, 21 and 22 that 90 percent of the bed is coarser than about 0.15 mm. Therefore, on plates 17, 18 and 19, only the portion of the suspended load coarser than 0.149 mm. represents "bed material load" for which a functional relationship between the bed characteristics and the flow characteristics can be expected to exist. The portion of the suspended load finer than 0.149 mm. is designated as "wash load," the transport rate of which does not depend significantly on the flow and bed conditions but is determined principally by how much is supplied by tributaries, caving banks, etc. Only the "bed material load" can be expected to show a correlation with bed changes, although the wash load might have some influence on the turbulence mechanism of the flow itself. It is significant that the suspended sand load coarser than about 0.149 mm. seems to show a systematic increase during the September to November period while the water temperature decreases. The concentrations of these coarse suspended sediments are generally very small and in some samples, smaller than the accuracy of measurement. For this reason the trends shown on the plates should be cautiously accepted. Comparison of plates 19 and 27 show the correlation between bed material load coarser than 0.149 mm. and other hydraulic factors in 1966.

Distribution of Bed Sediment. All the bed samples collected within the study reach were mathematically composited by averaging the data for each survey. The five, twenty-five and fifty percent finer sizes for these composites are shown on plate 30. Only a slight coarsening of the bed material during the 1966 study period is indicated. Comparisons were made to see if bed grain size varied longitudinally within the study reach but no trends were apparent.

The results of the bed samples collected at the Ak-Sar-Ben bridge in conjunction with suspended sediment sampling were also reviewed. No measurable increase in bed grain size could be noted by this evaluation, which is shown on plates 20, 21 and 22.

Effects of Temperature and Suspended Sediment on Water Viscosity. It is believed possible that the changes in viscosity may have an effect on the stage-discharge relationship. These changes, due to variations in temperature and suspended wash load, were investigated. Plate 31 shows that large suspended sediment concentrations do affect the viscosity but that the small concentrations (1,000 ppm or less) observed during the study do not. Viscosity does, however, change greatly with changes in water temperature regardless of concentration. It can be noted that larger variations in viscosity occur at relatively low temperatures than at higher temperatures for a given temperature change.

Water and Air Temperature Relationship. Comparisons of the mean daily air temperatures and water temperatures were made to determine the time lag between air and water temperature changes at Omaha. There is about a 3-day lag between the mean daily air and water temperature.

Effects of Wind on River Stage. An attempt was made to determine the effects of wind on river stage by comparing the stage shift occurring at the time of a discharge measurement with the wind velocity and direction. No correlation was noted using this method. It is planned to review the stage recorder charts with wind velocity and direction to see if this may show a correlation. However, no measurable effects are anticipated.

IV - SUMMARY

The data presented in this report are admittedly preliminary and probably not adequate to draw positive conclusions. However, it does establish observed trends and begins to provide a new logical basis for understanding the cause of seasonal rating curve shifts in the Missouri River. These are the principal results and some tentative conclusions of this study:

1. It is a seasonal characteristic for the water surface of the Missouri River at Omaha to lower between 1 and 2 feet during the fall period, September through November. During this period the discharge usually is reasonably steady at around 30,000 c.f.s. due to reservoir regulation of flows for navigation. The water temperature, however, decreases progressively 20 to 30 degrees during these fall months. The rating curve shift seems to be strongly correlated with water temperatures. No other significant correlative factor has been identified; however, isolated small rises in discharge do tend to produce shifts which, in some years partially obscure the temperature effect.

2. A series of special observations were made in a 7-mile study reach during the fall months of 1966. The discharge was reasonably steady in the range 31,000 to 34,000 c.f.s. The water temperature decreased progressively from 70^{o} to 40^{o}, and concurrently the rating curve shifted downward 1.5 feet. This shift was accompanied by a progressive increase in average channel velocity from 4.5 to 5.0 feet per sec. and a decrease in the "n" value from .020 to .015. The transport rate of bed material load (suspended load coarser than .149 mm) doubled, although the grain size analysis of the bed surface did not change appreciably. The water surface slope remained the same.

3. The average channel cross section in the reach, when compared to a fixed vertical datum, did not change significantly during the study period. This means that the channel neither degraded nor changed its shape during the period.

4. Longitudinal profiles sounded with a sonic sounder revealed a bed configuration consisting of sand dune areas and "flat" areas. As the fall period progressed the proportion of "flat" bed increased. Furthermore, the sand dunes increased in average length from about 200 to 500 feet and decreased in average height (trough to crest) from about 3.0 to 2.5 feet. The decrease in dune steepness (height to length ratio) correlated with the decrease in the "n" value.

5. Although the water surface shifted downward 1.5 feet in 1966 the average water depth over the top of the sand dunes actually increased slightly. We must be cautious in applying

this conclusion from the study because the analysis is based on only one longitudinal sounding trace through the reach for each survey; nevertheless, this is a most significant finding relative to the effect of the seasonal shift on navigation depths.

6. The findings in Items 2, 3 and 4 indicate that the seasonal rating curve shift is almost entirely the result of a change in hydraulic resistance and is not the result of degradation or any change in channel cross section. The change in boundary resistance must be attributed to changes in the sand dunes which tended to lengthen, flatten, and disappear while the "n" value decreased. Another factor affecting hydraulic resistance is the Prandtl turbulence constant K which is about 0.40 for clear water but which has been found to decrease in flows with suspended sand. Since the bed material load doubled during the study period, there may have been a significant change in K. Analysis of the suspended sediment point concentration and velocity distribution data may shed light on this question.

V - FUTURE SURVEYS AND ANALYSIS

Further observations of the same study reach will be initiated in August 1967 and continue through the navigation season. During these observations it is planned to concentrate more on longitudinal profile sounding and less on range profile sounding. Bed samples from the entire reach will be composited in the field and only one representative sample analyzed in the laboratory. Additional longitudinal sounding will be made on a short reach to ascertain whether the channel centerline profiles are representative of a major portion of the channel. Suspended sediment point samples and velocity distribution data will be collected from a tagline at some location in the study reach to eliminate the possible effect of the piers and channel restriction at the Ak-Sar-Ben bridge. An analysis will be made of all the past special sampling data taken at the Omaha station.

It is hoped that at the completion of the fall surveys, sufficient data will be available to draw more accurate conclusions and to predict both the time and the extent of future shifts. A more complete report will be assembled and made available as soon as practical.